Status of baseline Undulator e+ Source

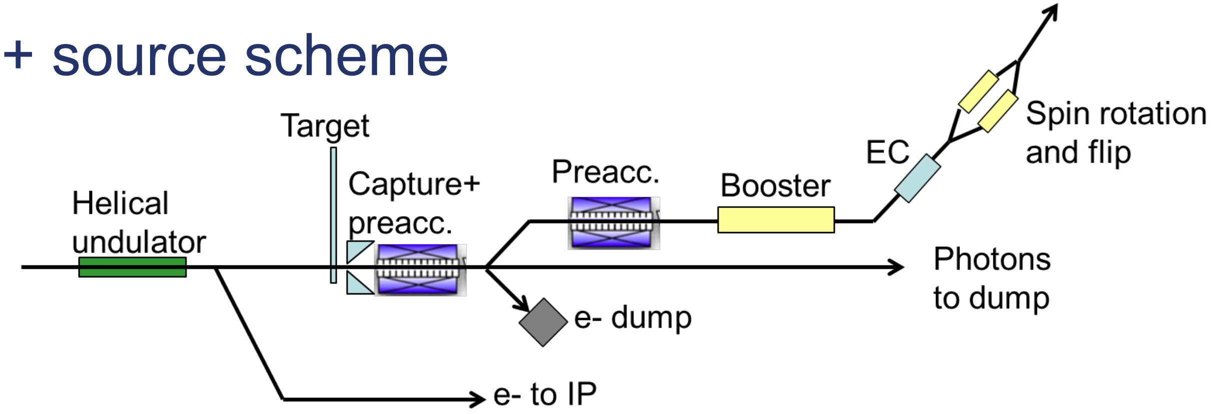
- **Status and Physics**
- **Ongoing work:**
  - **Undulator Simulations**
  - **Rotating Wheel Design**
  - **Target Material Analyses** ***(see Tim's talk)***
  - **Pulsed Solenoid** ***(see Carmen's talk)***
  - **Plasma Lens prototype and simulations** ***(see Manuel & Niclas' talks***
- **Conclusion and grant applications**

Gudrid Moortgat-Pick, Sabine Riemann, Peter Sievers

LINEAR COLLIDER COLLABORATION

TDR baseline layout of the e+ source

- The polarized e+ source scheme



Principle tested with
E-166 experiment @SLAC 2005

G. Alexander et al., NIMA 610 (2009), G. Alexander et al., Phys.Rev.Lett.100 (2008)

- ILC e+ beam parameters (nominal luminosity)

Number of positrons per bunch at IP	2×10^{10}
Number of bunches per pulse	1312
Repetition rate	5 Hz
Positrons per second at IP	1.3×10^{14}

  – Required positron yield: Y = 1.5e+/e-   at damping ring

Advantage baseline design: polarized e±

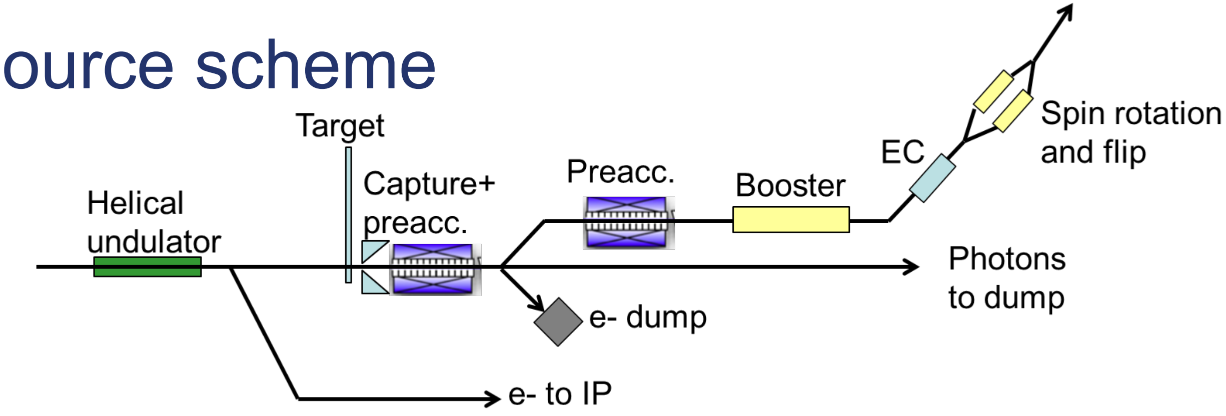
- **Important issue: measuring amount of polarization**
  - **limiting systematic uncertainty for high statistics measurements**
  - **Compton polarimeters (up- /downstream): envisaged uncertainties of ΔP/P=0.25%**
- **Adding positron polarization required:**
  - **Substantial enhancement of eff. luminosity and eff. polarization and independent observables**
  - **handling of limiting systematics and access to in-situ measurements: ΔP/P=0.1% achievable!**
  - **Windows to new physics already at ILC250 & GigaZ with less running time/operation cost**
- **Physics impact: Higgs-Physics, WW/Z/top-Physics, New Physics**

Literature: polarized e+e- beams at a LC (only a few examples)

- *LCC-Physics Group: 'The role of positron polarization for the initial 250 GeV stage of ILC', arXiv: 1801.02840*
- *G. Moortgat-Pick et al. (~85 authors) : `Pol. positrons and electrons at the LC', Phys. Rept. 460 (2008), hep-ph/0507011*
- *G. Wilson: `Prec. Electroweak measurements at a Future e+e- LC', ICHEP2016, R. Karl, J. List, LCWS2016, 1703.00214*
- *many more (only few examples): 1206.6639, 1306.6352 (ILC TDR), 1504.01726, 1702.05377, 1908.11299,2001.03011, …*
- *G. Moortgat-Pick, H. Steiner, `Physics opportunities with pol. e- and e+ beams at TESLA, Eur.Phys.J direct 3 (2001)*
- *T. Hirose, T. Omori, T. Okugi, J. Urakawa, Pol. e+ source for the LC, JLC, Nucl. Instr. Meth. A455 (2000) 15-24*

TDR baseline layout of the e+ source

The polarized e+ source scheme

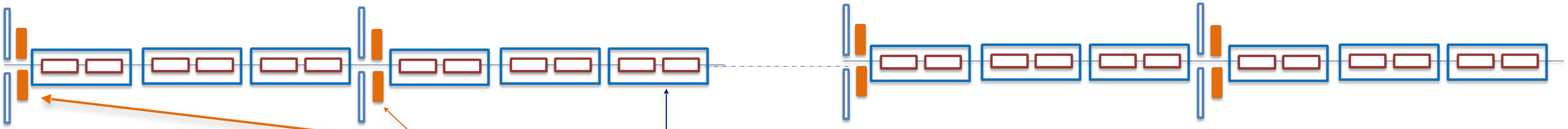


Work package	Items
WP-5: Undulator	Simulation (field,errors, alignment)
WP-6: Rotating target	Design finalization, partial laboratory test, mock-up design
	Magnetic bearings: performance, specification, test
	Full wheel validation, mock-up
WP-7: Magnetic focusing system	Design selection (FC, QWT, pulsed solenoid, plasma lens), with yield calculation
	OMD with fully assembled wheel

WP5 Undulator: Simulation (field errors, alignment)

- Misalignments:
  - beam spot increases slightly, yield decreases slightly *(**see A.Ushakov, AWLC18**)*
- Realistic undulator with B field (K) and period (λ) errors
  - Results consistent with previous works
  - provides beam size, polarization, target load
- Synchrotron radiation deposit in undulator walls
  - Masks protect wall to levels below 1W/m
  - ILC250: power deposition in 'last' mask near undulator exit: ~300W

Alharbi, Thesis 23



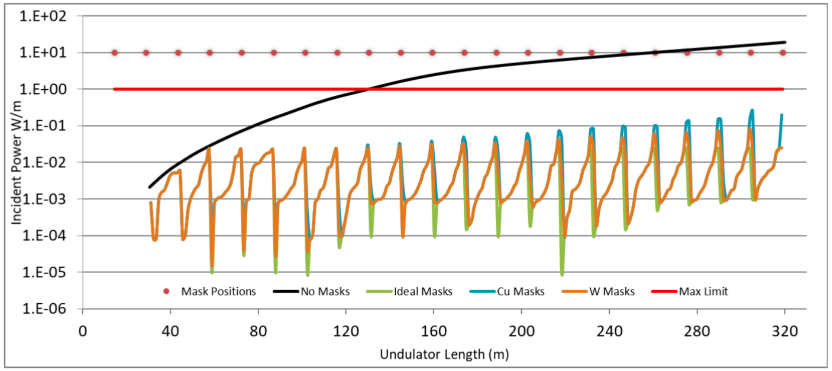
quadrupole

mask

Cryomodule with
2 undulator mudules

ILC250

- ***Result: Masks substantial but sufficient in all cases!***
- Studied for ILC250, ILC350, ILC500 and GigaZ !



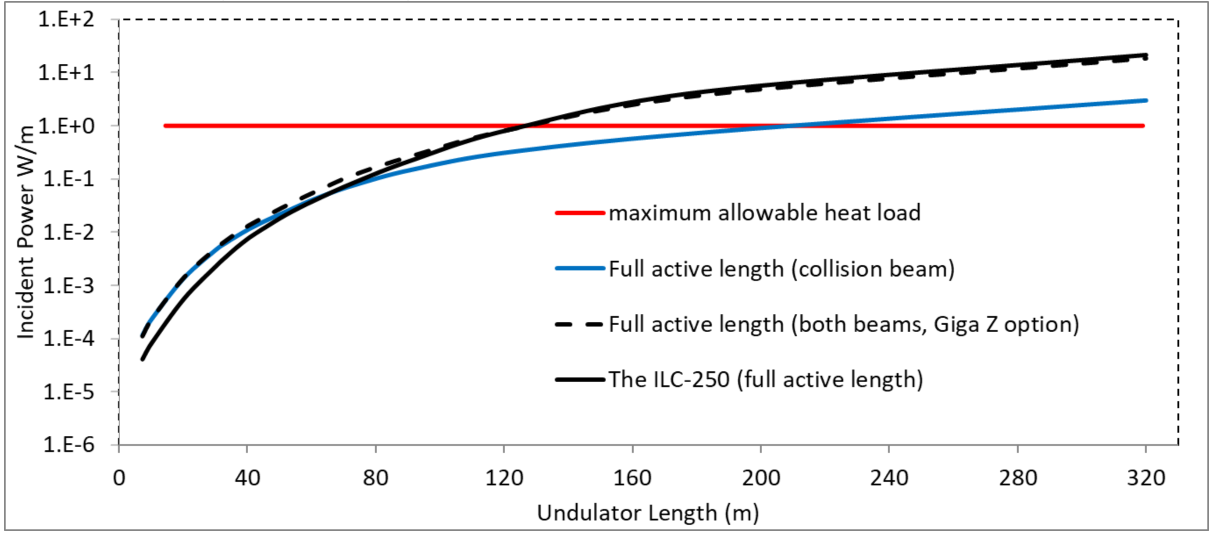
WP5: GigaZ operation

- Parameters for GigaZ operation

Yokoya-san, 1908.08212

Parameters	e^+ production	collision	Unit
Final beam energy	125	45.6	GeV
Average accelerating gradient	31.5	8.76	MV/m
Peak power per cavity	189	77.2	kW
Beam pulse length	0.727	0.727	ms
RF pulse length	1.65	1.06	ms
Repetition rate	3.7	3.7	Hz

- Incident power at undulator walls: Compare GigaZ and ILC250



power deposition in wall without masks

➡ Incident power at GigaZ below /comparable with ILC250

➡ Mask protection will also be sufficient for GigaZ running

WP-6: Rotating Target for Undulator Scheme

◆ Target specification

- Titanium alloy, 7mm thick (ILC250: 0.2 X_0), 14mm (ILC500), diameter 1m
- Rotating at 2000 rpm (100 m/s) in vacuum
- Photon power ~60 kW, deposited power ~2 kW
- Radiation cooling
- Magnetic bearings, widely used for Fermi choppers, vacuum pumps and fast rotating masses

✦ Ongoing target material tests (see Tim's talk on Thursday!)

- Tested: T-rise more critical for target damage than radiation
- Result: phase transitions possible, but T-rise not critical: targets are safe at ILC!

◆ R&D to be done as WP-prime

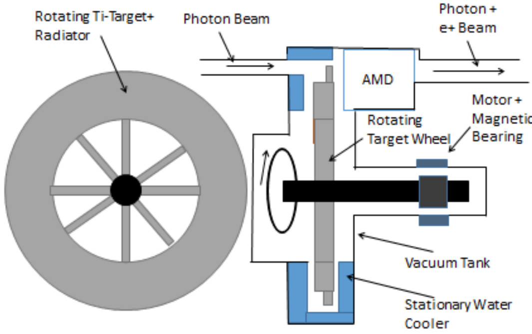
- Detailed simulations in close contact with OMD design on-going (Carmen's talk)
- OMD Design finalization, laboratory test of mock-up design
- Magnetic bearings: technical specifications done, ready for feasibility study, engineering design, test (in the remaining years)

WP6: R&D activities rotating wheel

Drive and bearings

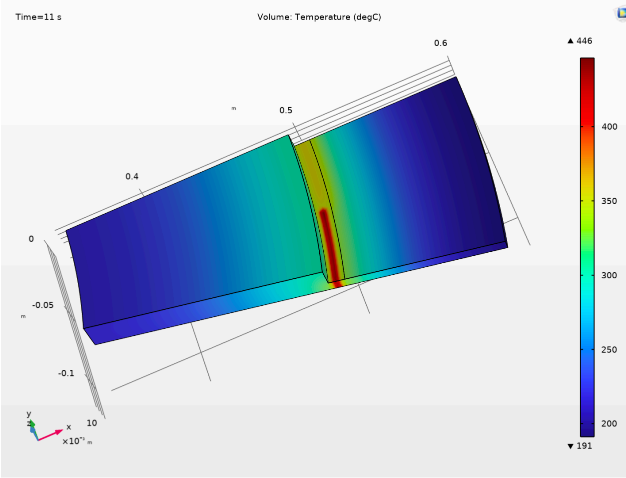
- Radiation cooling allows magnetic bearings
  - A standard component to support elements rotating in vacuum.
  - The axis is «floating» in a magnetic field, provided by permanent or electro magnets

Principal Layout: Ti-Wheel with a Diameter of 1.0 m, rotating at 100 m/s, 2000 rpm.



- For the specific ILC-application, a technical specification of for performance and boundary conditions required
  - Specification to be done based on simulation studies
  - New simulations studies under work in close collaboration with pulsed solenoid simulations
  - Discussion started with construction people at DESY

S., Patra 2022



Analyses of ILC targets

see Tim's talk on Thursday!

- target material tested at Mainz Microtron (MAMI) using e-
  - Done: electron-beam on ILC target materials, generating cyclic load with same/ even higher PEDD at target than expected at ILC

A. *Ushakov*

  - Several successful tests performed on Ti-Alloy

T. Lengler, BThesis 2020

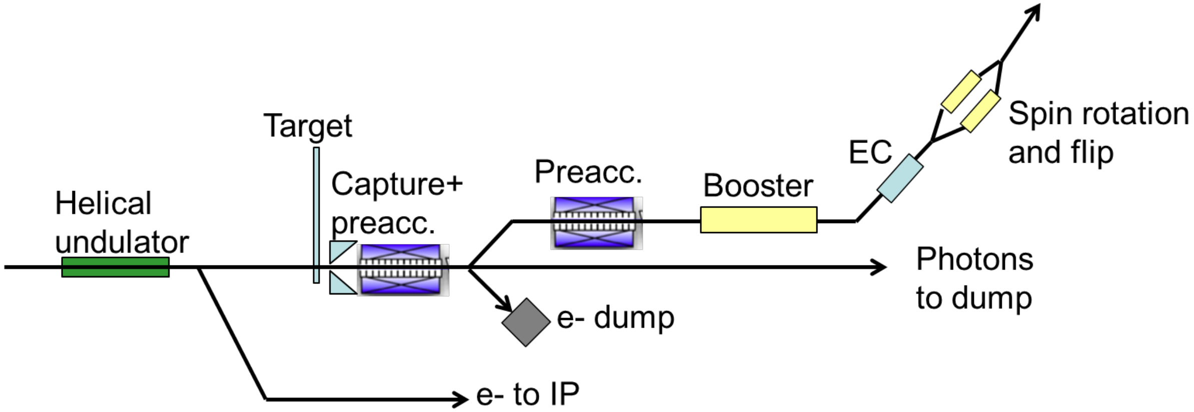
➡ Result: ILC undulator target will stand the load

  - Further tests in 22 and 23
- Ongoing: disentangling target damage originating from thermal vs radiation load
  - with dilatometer: targets at high temperature
  - fast and cyclic stress in the range of 400^0-800^0C
  - variation of T_{max} , heating rate, fixed T
  - very interesting results with α- and β- phase of Ti-alloy

T. Lengler, MThesis 2023

- Result: ILC undulator target will stand the load

WPP-7: Focusing System for Undulator Scheme



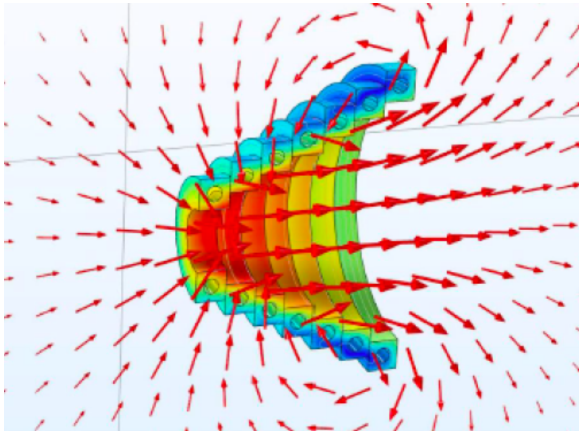
- ◆ The critical item for the undulator scheme is the magnetic focusing system right after the target
- ◆ Possible candidates are: (a) Pulsed solenoid, (b) Plasma lens
- ◆ The strongest candidate is (a) pulsed solenoid.
- ◆ R&D items to be done as WP-prime
  - ➢ Detailed simulations for (a) (already on-going)
  - ➢ Principal design & engineering for a prototype pulsed solenoid
  - ➢ Field measurements with 1kA (pulsed and DC) and with 50kA both in a single pulse mode and finally with pulse duration of 5ms at 5 Hz
  - ➢ Prototype plasma lens (funded study on-going)

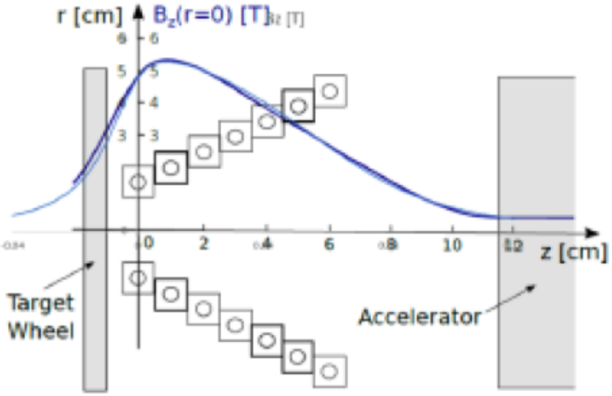
OMD Design: Pulsed Solenoid

‘Baseline’: Pulsed Solenoid (see Carmen’s talk, in 5 minutes):

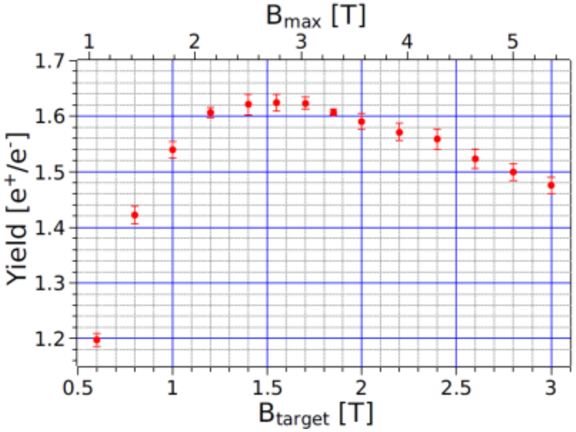
- Yield of e+ (OMD&capture Linac): 1.64-1.81 Fukuda-san, 2021
- Within ITN initiative: manufacturing drawings at DESY until fall
- Windings, coils, etc. in discussion with e.g. Rossendorf
- Planned: prototype tests
- Further grant application under way

M. Mentink, C, Tenholt, G. Loisch, 2021





Yield versus field on the target

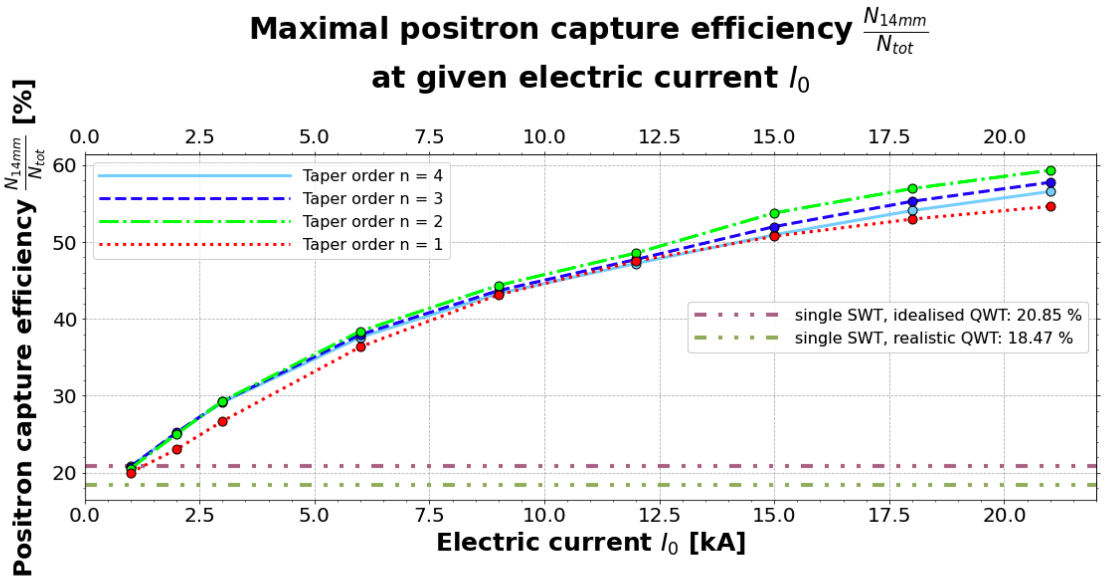


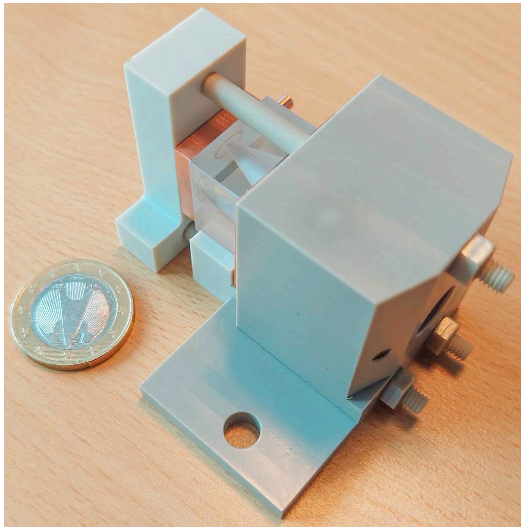
OMD Design: Plasma Lens

Formela, Hamann, Loisch

‘Future’: Plasma Lenses (see Manuel&Niclas’ talks on Thursday)

- increases e+ yield but increases load at target only slightly
- advantages in matching aspect
- downscaled prototype designed and produced
- first measurement start this month
- further grant application for full prototype under work





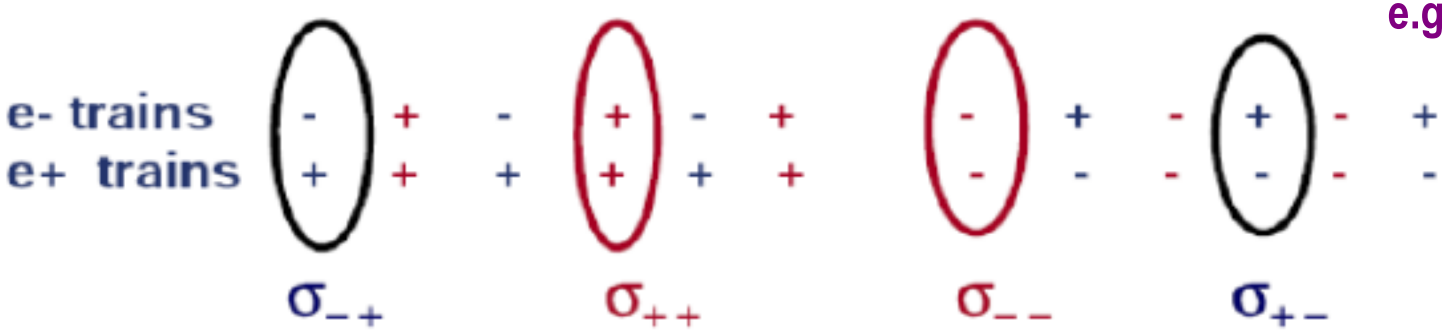
Conclusion and plans

- Undulator-based positron source mature design
  - offers in addition polarized e+
- Advanced work on mask designs, OMD prototypes (pulsed solenoid, Plasma lens) and material target tests
  - efforts&simulations ongoing on rotating wheel prototype design
  - tests: favourable to revive UK spinning target for further mechanical tests, maybe together with US….., separate cooling tests with target pieces
- Grant applications (BMBF) under way for full prototype plasma lens, and pulsed solenoid&rotating wheel
- Inclusion of e+ source for HALHF concept

Why is helicity flipping required?

- Gain in effective lumi lost if no flipping available

e.g. S. Riemann



  - 50% spent to ‘inefficient’ helicity pairing (most SM, BSM)
  - Similar flip frequency for both beams ~ pulse-per-pulse
- Gain in ΔP_{eff} remains, but flipping required to understand:
  - Systematics and correlations $P_{e-} \times P_{e+}$
- Spin rotator before DR and spinflipper has been set-up!
  - See TDR, Sect. 3.1 and CR08 (approved)

L. Malysheva ‘13

Polarization basics

- **Longitudinal polarization:** $\mathcal{P} = \dfrac{N_R - N_L}{N_R + N_L}$
- **Cross section:**

$$\begin{aligned}\sigma(\mathcal{P}_{e^-}, \mathcal{P}_{e^+}) &= \frac{1}{4}\{(1+\mathcal{P}_{e^-})(1+\mathcal{P}_{e^+})\sigma_{\rm RR} + (1-\mathcal{P}_{e^-})(1-\mathcal{P}_{e^+})\sigma_{\rm LL} \\ &\quad +(1+\mathcal{P}_{e^-})(1-\mathcal{P}_{e^+})\sigma_{\rm RL} + (1-\mathcal{P}_{e^-})(1+\mathcal{P}_{e^+})\sigma_{\rm LR}\}\end{aligned}$$

- **Unpolarized cross section:**

$$\sigma_0 = \frac{1}{4}\{\sigma_{\rm RR} + \sigma_{\rm LL} + \sigma_{\rm RL} + \sigma_{\rm LR}\}$$

- **Left-right asymmetry:** $A_{\rm LR} = \dfrac{(\sigma_{\rm LR} - \sigma_{\rm RL})}{(\sigma_{\rm LR} + \sigma_{\rm RL})}$
- **Effective polarization and luminosity:**

$$\mathcal{P}_{\rm eff} = \frac{\mathcal{P}_{e^-} - \mathcal{P}_{e^+}}{1 - \mathcal{P}_{e^-}\mathcal{P}_{e^+}} \qquad \mathcal{L}_{\rm eff} = \frac{1}{2}(1 - \mathcal{P}_{e^-}\mathcal{P}_{e^+})\mathcal{L}$$

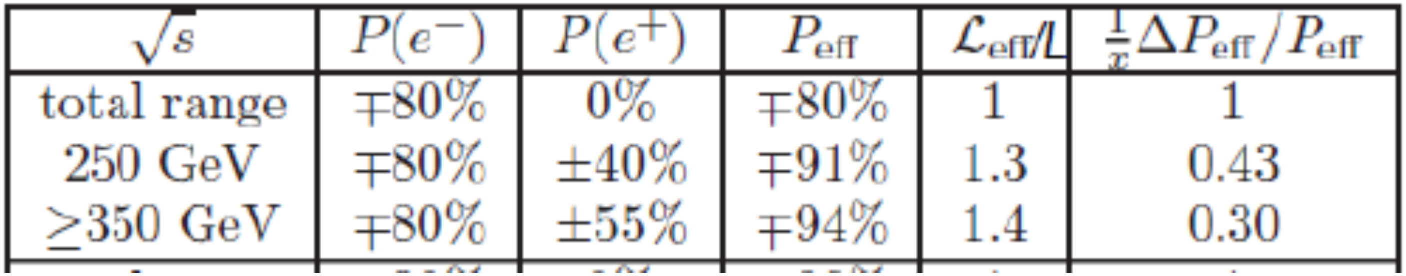
Why is helicity flipping required?

- **With both beams polarized we gain in**
  - **Higher effective polarization (higher effect of polarization)**

$$P_{\rm eff}:=(P_{e-}-P_{e+})/(1-P_{e-}P_{e+})$$

  - **Higher effective luminosity (higher fraction of collisions)**

$$L_{\rm eff}/L=1-P_{e-}\,P_{e+}$$



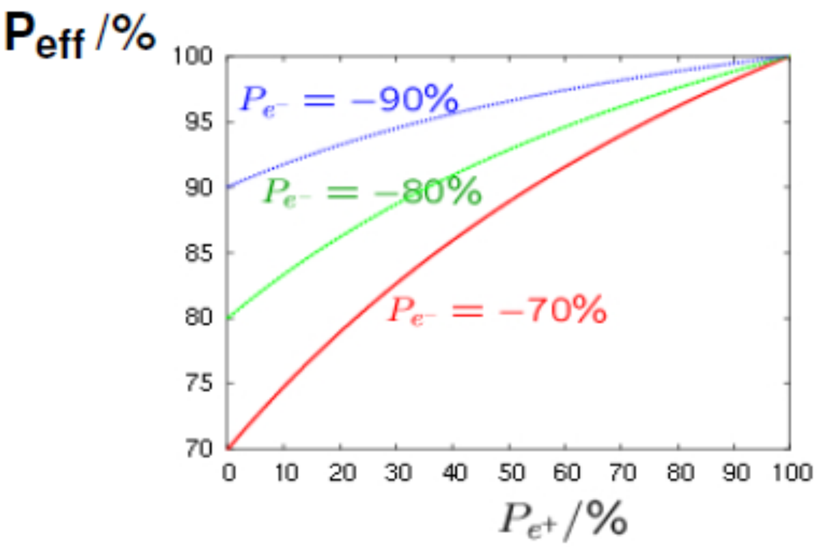
$\sqrt{s}$	$P(e^-)$	$P(e^+)$	$P_{\rm eff}$	$\mathcal{L}_{\rm eff}/L$	$\frac{1}{x}\Delta P_{\rm eff}/P_{\rm eff}$
total range	∓80%	0%	∓80%	1	1
250 GeV	∓80%	±40%	∓91%	1.3	0.43
≥350 GeV	∓80%	±55%	∓94%	1.4	0.30

- **Applicable for V,A processes (most SM, some BSM)**

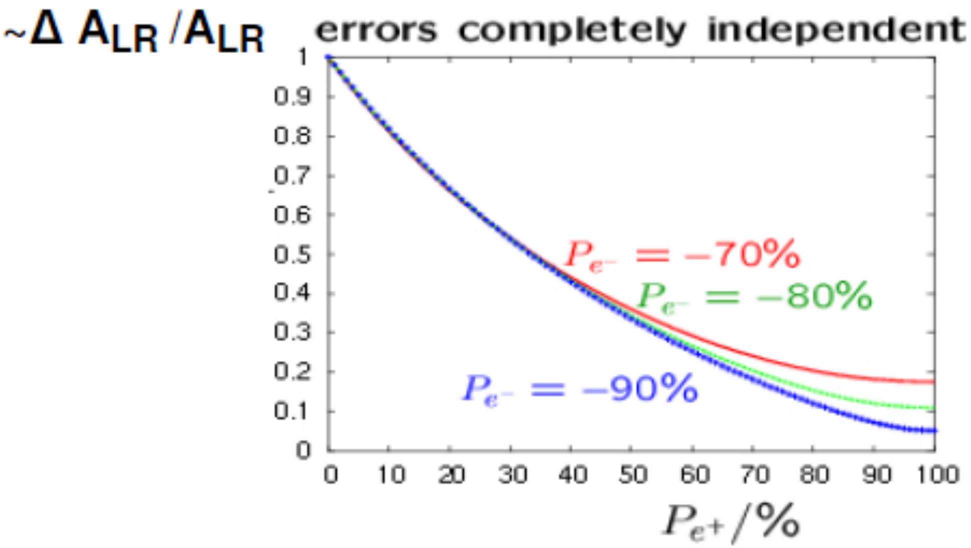
$$\sigma\,(Pe-,Pe+)=(1-Pe-\,Pe+)\,\sigma_{\rm unpol}\,[1-P_{\rm eff}\,A_{LR}]$$

Impact of P(e+)

- **Statistics**



- **And gain in precision**



	(80%,60): P_{eff} = 95%	(90%,60%): P_{eff} =97%	(90%, 30%): P_{eff} =94 %
	$\Delta A_{LR}/A_{LR}$ = 0.3	Δ A_{LR}/A_{LR} = 0.27	Δ A_{LR}/A_{LR} =0.5
gain:	factor~3	factor>3	factor~2

- NO gain with only pol. e- (even if '100% ') !

L_{eff} and P_{eff}

- **More concrete: If only LR and RL contributions: only 50 % of collisions useful**

effective luminosity: $L_{\mathrm{eff}}/L = \frac{1}{2}(1 - P_{e^-} P_{e^+})$

This quantity = the effective number of collisions, can only be changed with P_{e-} and P_{e+}:

here:

With ∓80%, ±30%, the increase is 24%

With ∓80%, ±60%, the increase is 48%

With ∓90%, ±60%, the increase is 54%

In other words: ***no P_{e+} means 24% more running time (!)***

and

10% loss in P_{eff} = 10% loss in analyzing power!

Quite substantial in Higgs strahlung and electroweak 2f production !

L_{eff} and P_{eff}: further example

- **Charged currents, i.e. t-channel W- or ν-exchange (A_{LR}=1):**

$$\sigma(\mathcal{P}_{e^-}, \mathcal{P}_{e^+}) = 2\sigma_0(\mathcal{L}_{\text{eff}}/\mathcal{L})[1 - \mathcal{P}_{\text{eff}}]$$

In other words: *no P_{e+} means 30% more running time needed !*

Quite substantial in Higgs production via WW-fusion!

Polarization measurement

- **Compton polarimeters: up- and downstream**
  - envisaged uncertainties of ΔP/P=0.25% (at polarimeters!)
  - But that’s is not enough for IP!
- **Use collision data to derive luminosity-weighted polarization**
  - single W, WW, ZZ, Z, etc.: combined fit

$$P^-_{e\pm} = -|P_{e\pm}| + \tfrac{1}{2}\delta_{e\pm} \qquad P^+_{e\pm} = |P_{e\pm}| + \tfrac{1}{2}\delta_{e\pm}$$

Karl, List,1703.00214

  - assume H-20 set-up concerning lumi
  - helicity reversal is important
  - non-perfect helicity-reversal can be compensated
  - 0.1% accuracy in ΔP/P is achievable at IP!
  - *NOT achievable without Pe+!*

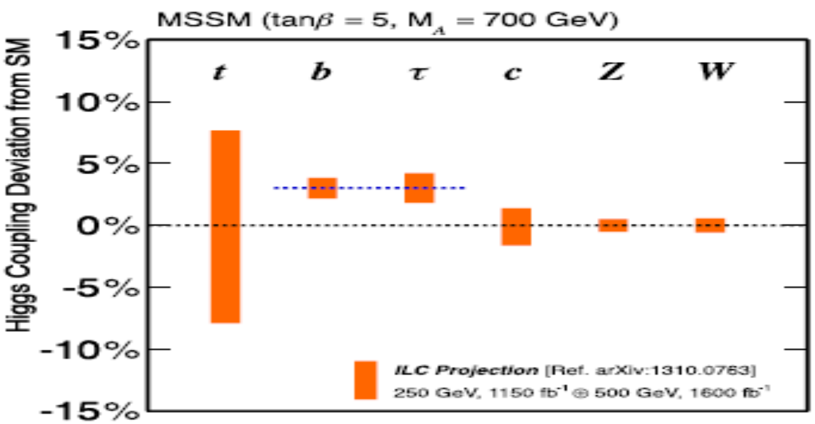
Remember: even if no Pe+ (SLC! dedicated experiment at SLACs Endstation A), the P_{e+}~0.0007 had to be derived a posteriori for physics reason!

Status Higgs

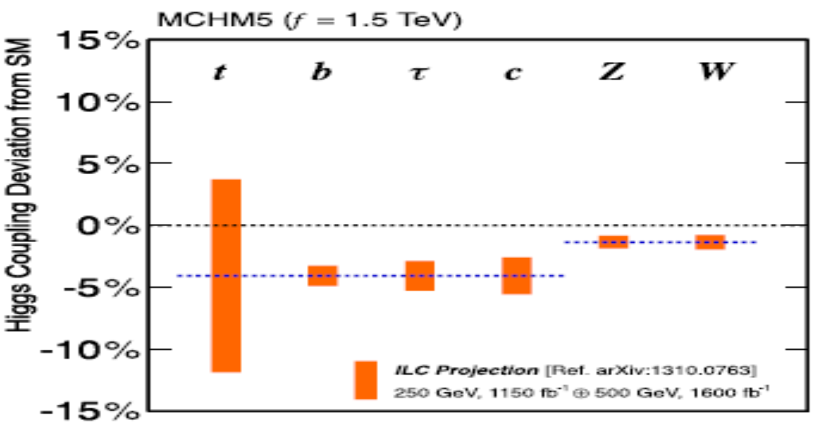
- Higgs within achievable accuracy at LHC: SM-like
  - Could be the only SM Higgs (what's about DM? gauge unification?)
  - Could be a SUSY Higgs (one has to be close to a SM-like one)
  - Could be a composite state

S. Komamiya, LP15

Supersymmetry
(MSSM)



Composite Higgs
(MCHM5)



ILC 250+500 LumiUp

- *Determination of Higgs couplings in 1% level essential for ILC250!*